

# Interactive Exploration Robots

Human-robotic collaboration and interactions



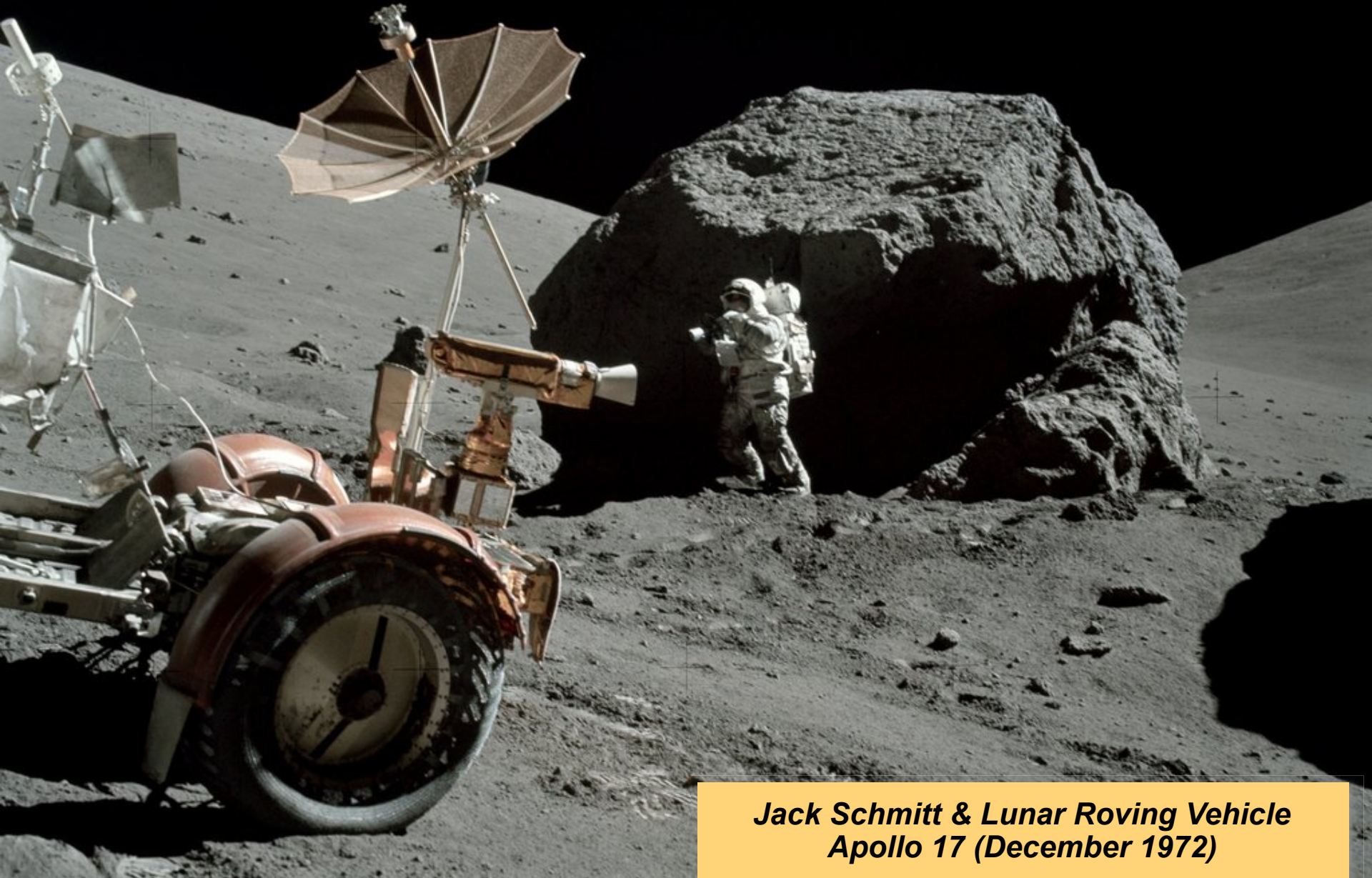
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[irg.arc.nasa.gov](http://irg.arc.nasa.gov)



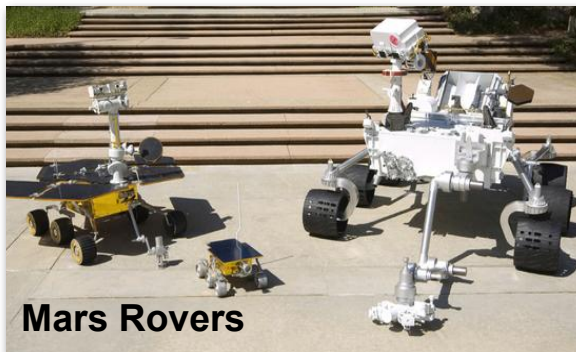
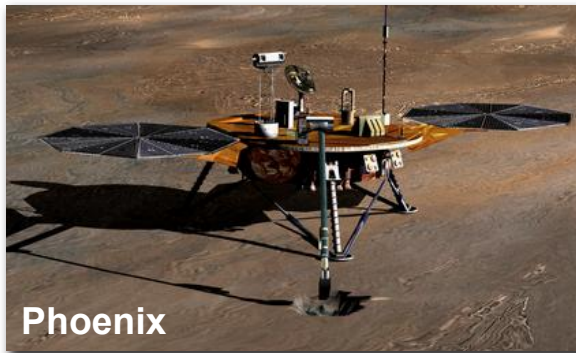
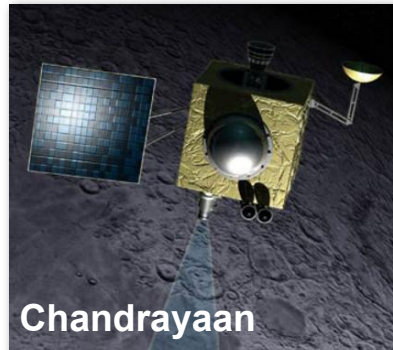
# Human Planetary Exploration



***Jack Schmitt & Lunar Roving Vehicle  
Apollo 17 (December 1972)***



# What's changed since Apollo?



# Human-Robot Teams

## Many forms of human-robot teaming

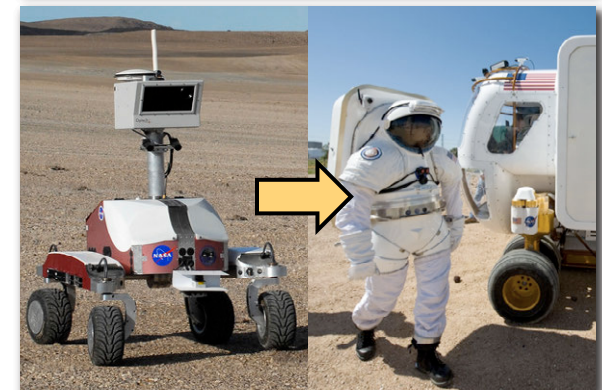
- “Robot as tool” is only **one** model
- Humans and robots do **not** need to be just co-located or closely coupled
- ▶ **Distributed teaming is also important**

## Concurrent, interdependent operations

- Human-robot interaction is still **slow** and **mismatched** (compared to human teams)
- Easy for robots to slow down the human
- ▶ **Loosely-coupled teaming (in time and space) should also be employed**

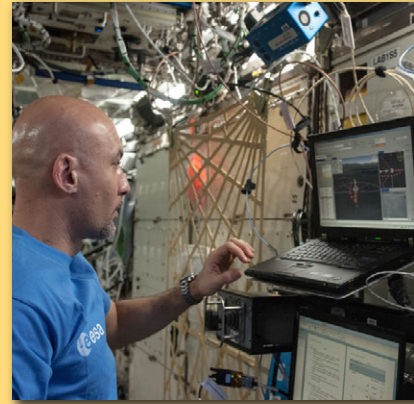
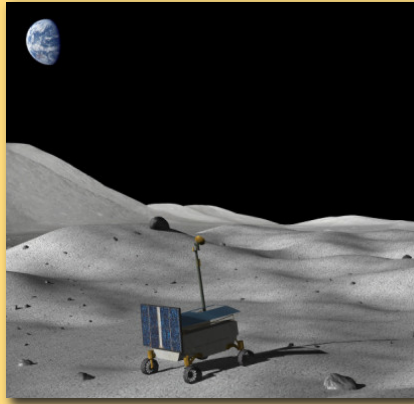
## Distributed teams

- Require **coordination** and **info exchange**
- Require understanding of (and planning for) each teammate’s **capabilities**





# Interactive Exploration Robots



## PART 1

Humans on Earth  
Robot in space

## PART 2

Humans on Earth  
Robot on the Moon

## PART 3

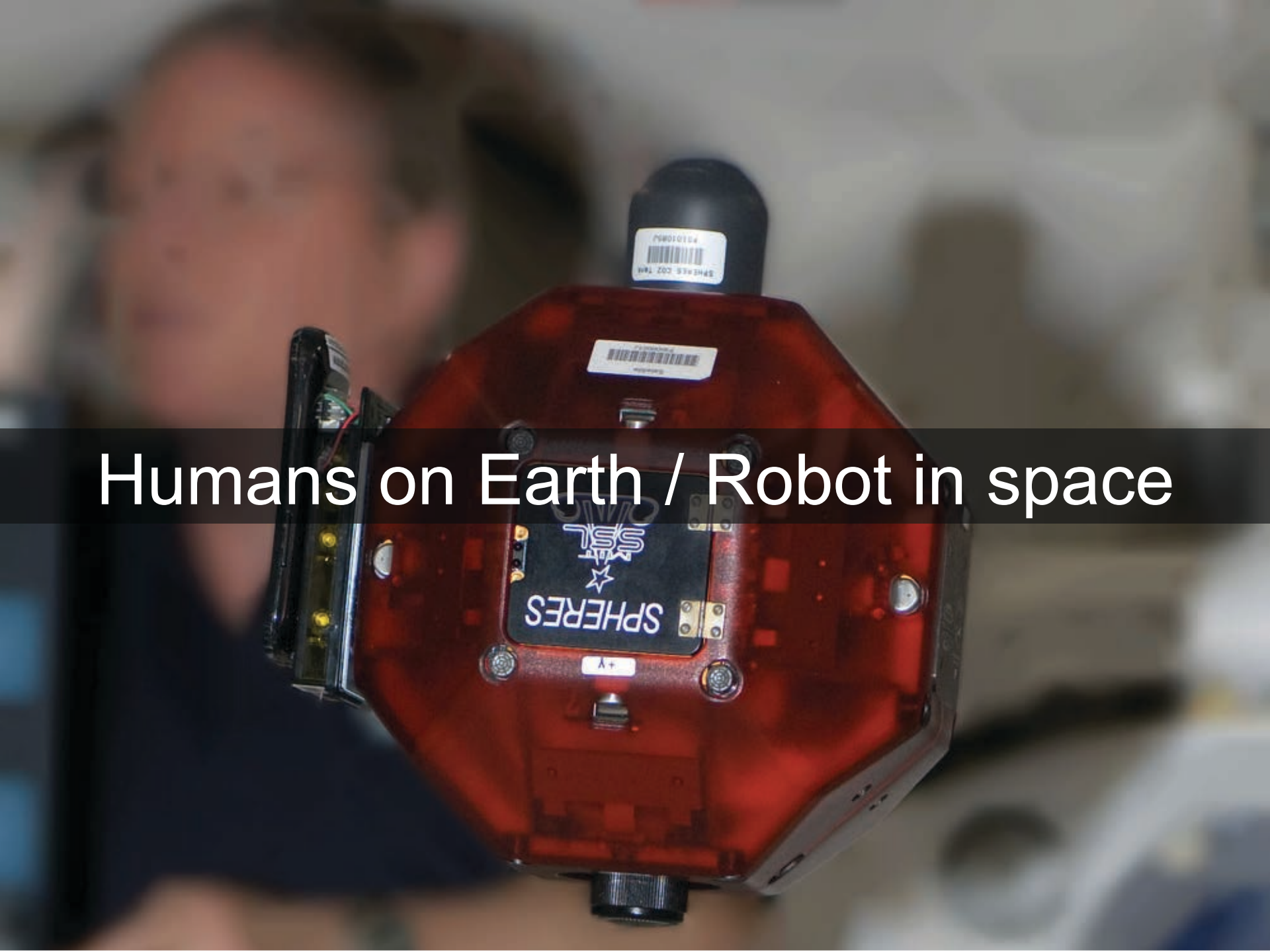
Humans in orbit  
Robot on planet

## PART 4

Real-time  
telerobotics





A red, octagonal satellite component, likely a CubeSat, is the central focus. It has a black label with the word 'SPHERES' in white, a star logo, and 'MIT' text. A small white label with 'Y+' is also visible. The component has a black cylindrical protrusion at the top and a black knob at the bottom. A person's face is blurred in the background. A semi-transparent black banner with white text is overlaid across the middle.

Humans on Earth / Robot in space



# Space Station In-Flight Maintenance

## Extra-Vehicular Activity (EVA)

- Not enough crew time to do everything (**only 1-2 EVAs per year**)
- Crew must always carry out “Big 12” contingency EVA’s if needed
  - Maintain electrical power system
  - Maintain thermal control system
- Prep & tear down: up to 3 hr per EVA



## Intra-Vehicular Activity (IVA)

- Crew spends a lot of IVA time on maintenance (**40+ hr/month**)
- Routine surveys require 12+ hr/month
  - Air quality, lighting, sound level, video safety, etc.
- Crew must always carry out contingency IVA surveys
  - Find and repair leaks, etc.





# Space Station Robots



**Space Station Remote Manipulator System (Canadarm2)**





# Space Station Robots



**Special Purpose Dexterous Manipulator (“Dextre”)**



*Human-robotic collaboration and interactions for space exploration*



# Space Station Robots



Robonaut 2



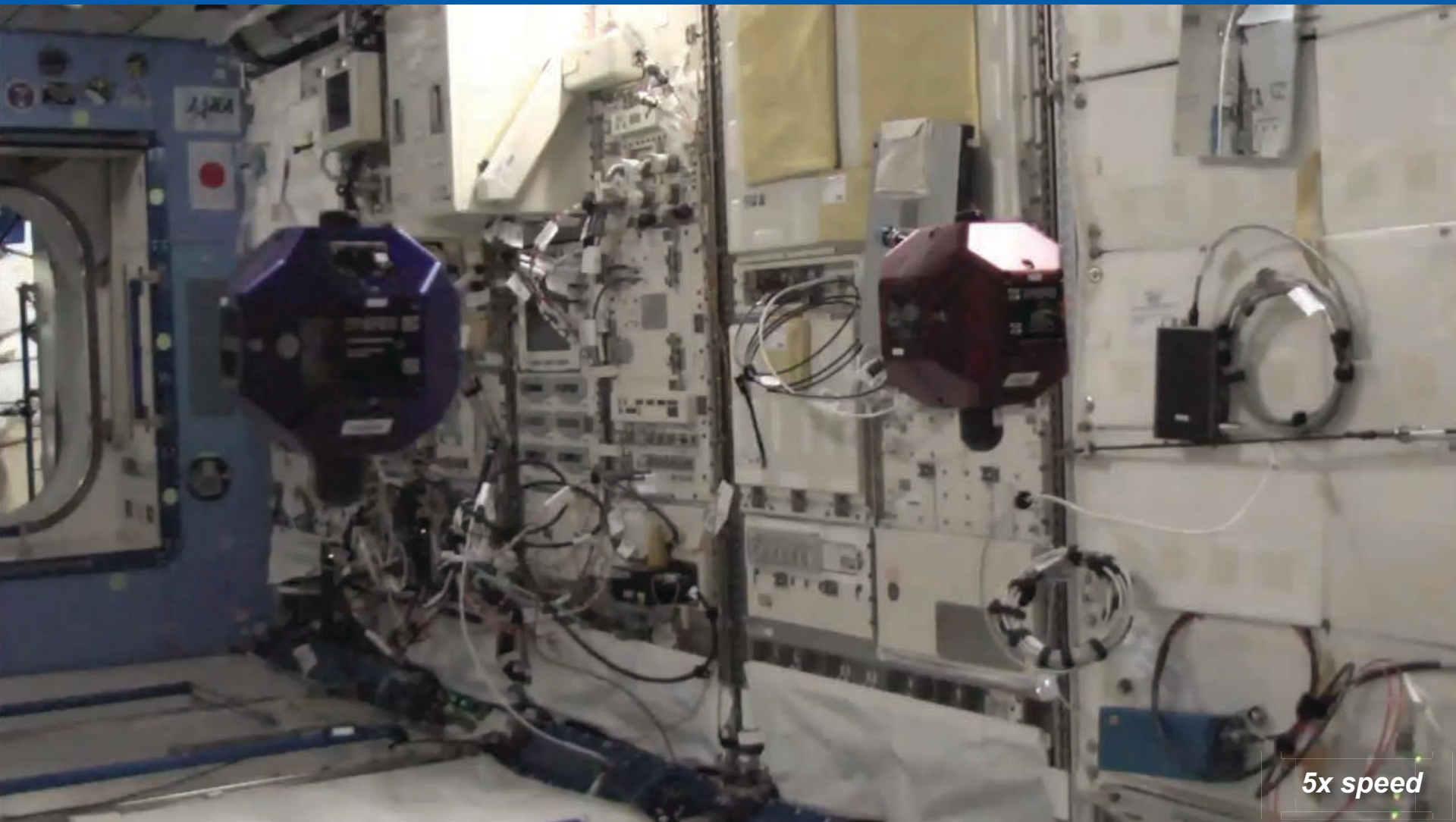
SPHERES



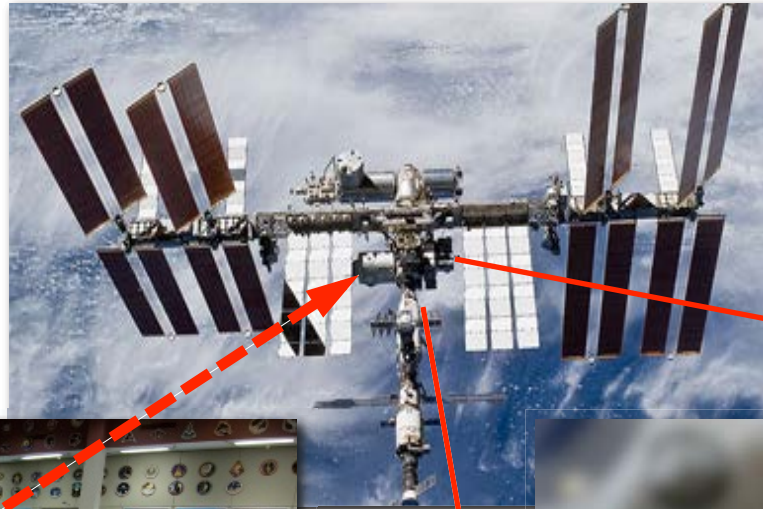
Astrobee (concept)



# SPHERES



# Smart SPHERES



ISS Mission Control  
(Houston)

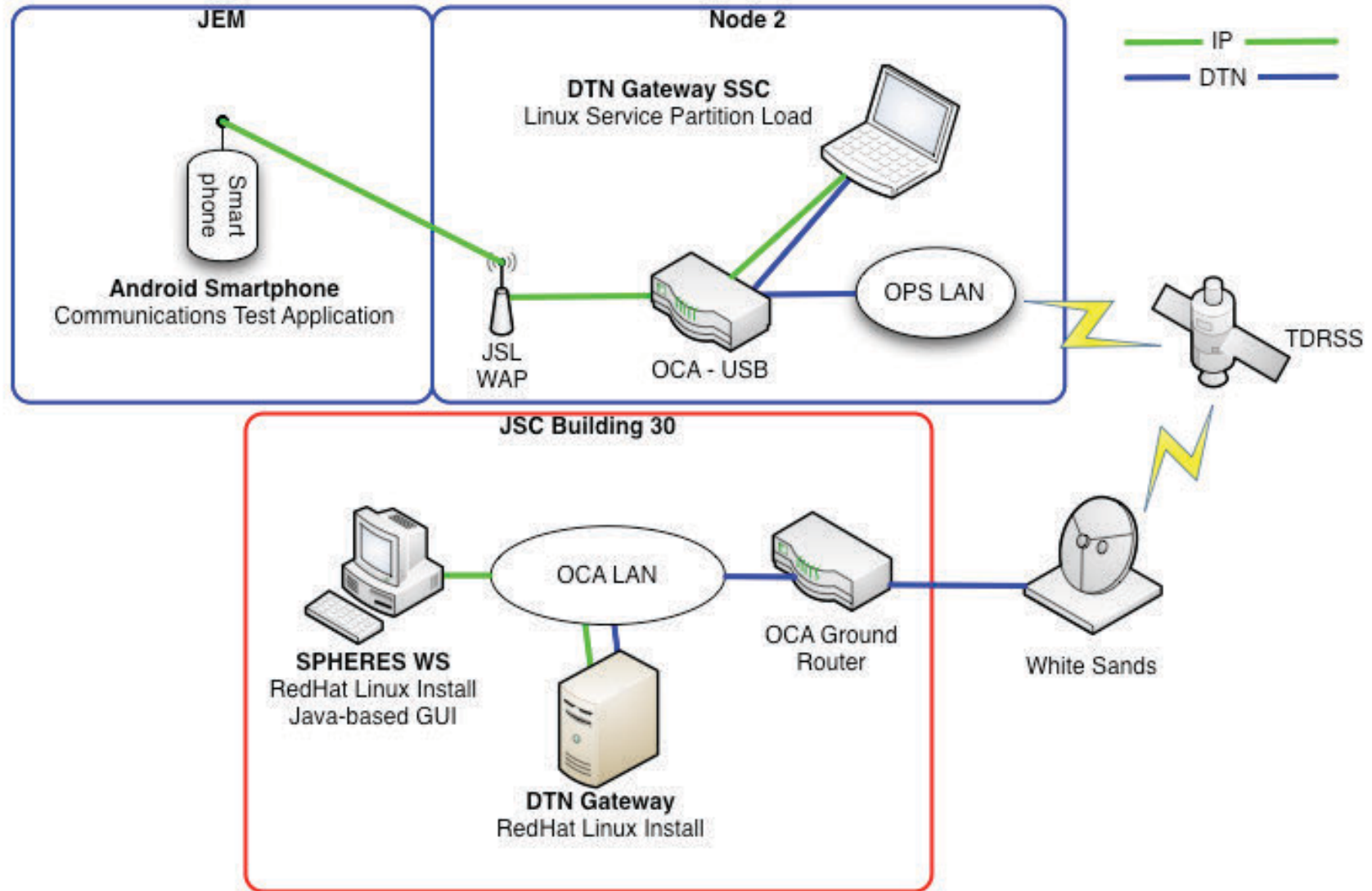


Smart  
SPHERES

T. Fong, M. Micire, et al. (2013) **“Smart SPHERES: a telerobotic free-flyer for intravehicular activities in space”**. Proc. of AIAA Space 2013 (Pasadena, CA).



# Smart SPHERES Network Setup



# Space Station Interior Survey (2012)







Humans on Earth / Robot on another world

# Mars Rovers



**Mars Exploration Rover on Mars  
(artist concept)**



**Curiosity at “Big Sky”**



# Resource Prospector Mission

## Mission

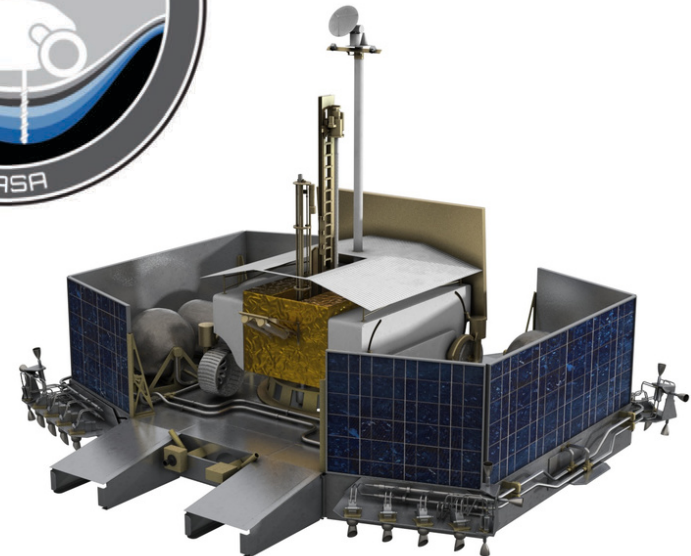
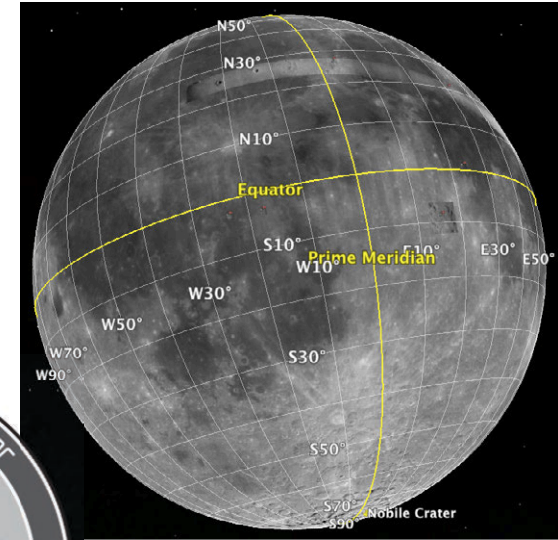
- Characterize the nature and distribution of **lunar polar volatiles**
- Demonstrate **in-situ resource utilization**: process lunar regolith

## Key Points

- Class D / Category 3 Mission
- Launch: ~2021
- Duration: 6-14 Earth days
- Direct-to-Earth communications
- **Real-time subsurface prospecting**

## Rover

- Mass: 300 kg (including payload)
- Size: 1.4m x 1.4m x 2m
- Max speed: **10 cm/s**
- Speed made good: **0.5 cm/s**

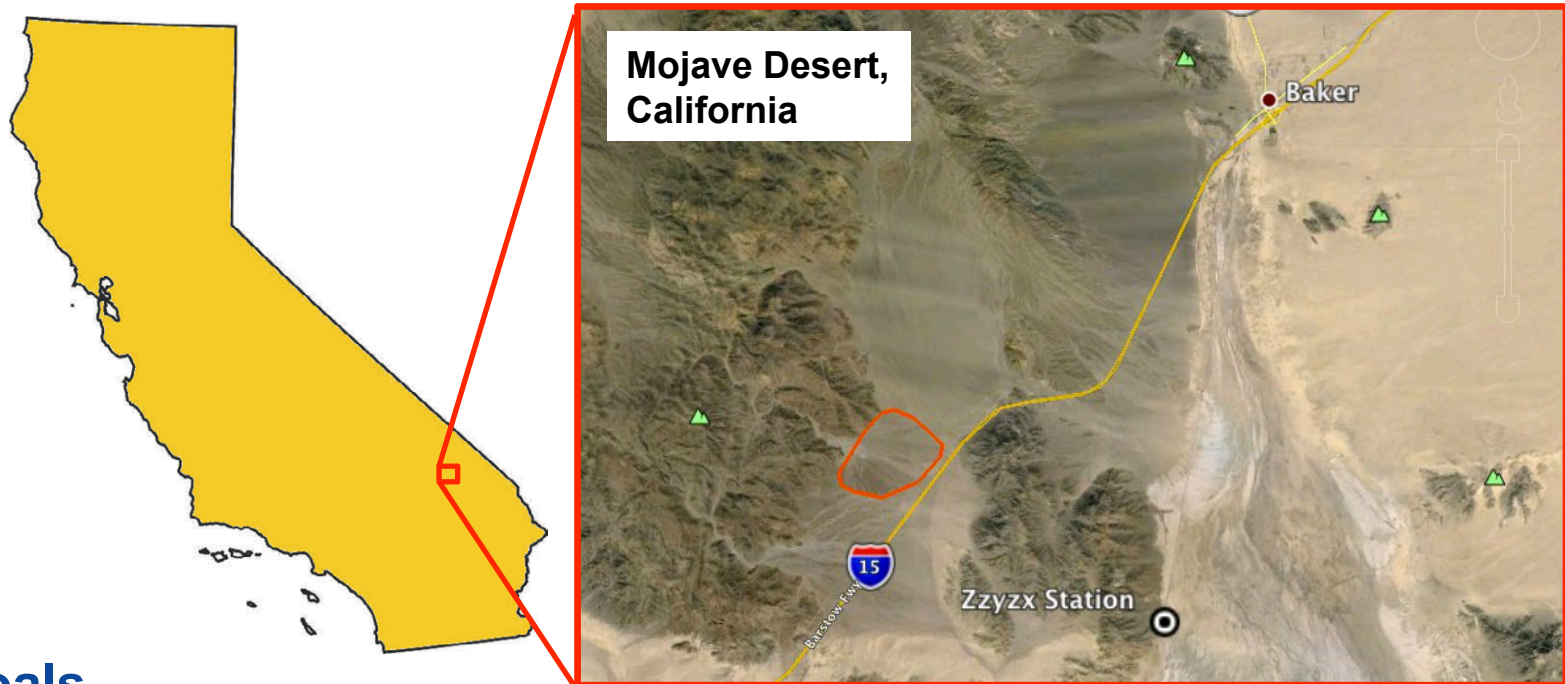


# RP Mission Animation





# Real-time Prospecting Field Test (2014)



## Goals

- **Prospecting.** Mature prospecting ops concept for NIRVSS and NSS instruments in a lunar analog field test
- **Real-Time Operations.** Improve support software by testing in a setting where the abundance / distribution of water is not known a priori
- **Science on Earth.** Understand the emplacement and retention of water in the Mojave Desert by mapping water distribution / variability

# Prospecting Rover and Instruments



**Sample Evaluation**  
Near Infrared Volatiles  
Spectrometer System

**Resource Localization**  
Neutron Spectrometer  
System



# Real-time Operations (NASA Ames)



# Mojave Volatiles Prospector

Mojave Desert, California

October 2014





# Rover Operator Interface (VERVE)

The screenshot displays the Verve for RAPID interface, which is used for managing rover operations. The main window shows a 3D terrain view with a planned path and various mission parameters.

**Plans on the rover:**

Name	ID	Version	Duration
MVP_2151_A_P21_ASOC	MVP2151_A_PLAN	A	02:2
Checkout Basic	MVP2151_B_PLAN	B	00:5
MVP_2388_A_P21_ASOC	MVP2388_A_PLAN	A	01:4

**Plans on the local file system:**

Name	ID	Version	Duration
MVP_2150_A_P21_AS1	MVP2150_A_PLAN	A	00:52:06
MVP_2151_A_P21_AS1	MVP2151_A_PLAN	A	02:38:03
Checkout Basic	MVP2151_B_PLAN	B	00:08:38
Checkout Traverse	MVP2152_A_PLAN	A	00:09:08
MVP_2388_A_P21_AS1	MVP2388_A_PLAN	A	00:27:25

**Run Plan Details:**

Name: MVP\_2168\_A\_P21\_ASOC  
 ID: MVP2168\_A\_PLAN  
 Version: A  
 Description: Optional raster  
 Est Duration: 01:49:38  
 State: Running

**Process Manager:**

State	Name
Running	KRex2_Controller
Running	KRex2_RT1_LegRecorder
Running	GroundCam Image Compressor

**Log Monitor:**

```

4445 [ [CTRL] TRAPECED, POS_ABS, -77.867deg, 177.617deg/s, 332.423deg/(s*s))
4446 [ [CTRL] TRAPECED, POS_ABS, -34.935deg, 98.583deg/s, 206.766deg/(s*s))
4447 [ [CTRL] TRAPECED, POS_ABS, 76.495deg, 175.553deg/s, 368.095deg/(s*s))
4448 driving profile:
4449 [ [CTRL] TRAPECED, POS_REL, -478.34deg, 25.82deg/s, 658.901deg/(s*s))
4450 [ [CTRL] TRAPECED, POS_REL, 286.617deg, 14.991deg/s, 394.791deg/(s*s))
4451 [ [CTRL] TRAPECED, POS_REL, -473.64deg, 24.775deg/s, 652.457deg/(s*s))
4452 [ [CTRL] TRAPECED, POS_REL, 278.729deg, 14.579deg/s, 383.939deg/(s*s))
  
```



# Science Operations Interface (xGDS)

xGDS Exploration Ground Data Systems  
**NASA MVP**

Intelligent Robotics Group  
National Aeronautics and Space Administration

Home Maps Console Log **Plans** Instruments Images Notebook System Status Search Beta Logout

List Plans Manage Schedule Planner Help Edit MVP\_2163\_B\_PZ1\_ASOC

Navigate Edit Stations Add Stations ☒ Auto until Google Earth Cut Copy Paste Delete Reverse Undo Redo Save As Save

Meta **Sequence** Layers Tools Links

Stations/Segments

Start	00:00
63 meters	+10:52
1	10:52
97 meters	+16:26
2	27:18
103 meters	+17:29
3	44:48
119 meters	+20:07
4	01:09:56
43 meters	+07:34
5	01:17:30
105 meters	+17:49
6	01:35:19
41 meters	+07:05
End	01:42:25

Station Start

Station Properties

GroundCam\_Start 00:00  
Nirvss\_Start 00:00  
Nss\_Start 00:00  
Add commands

Station Properties

Name

Notes

Id MVP2163\_B\_STN00

Coordinate System Lng, Lat

Lon, Lat -116.1902567, 35.1807235

Lon, Lat

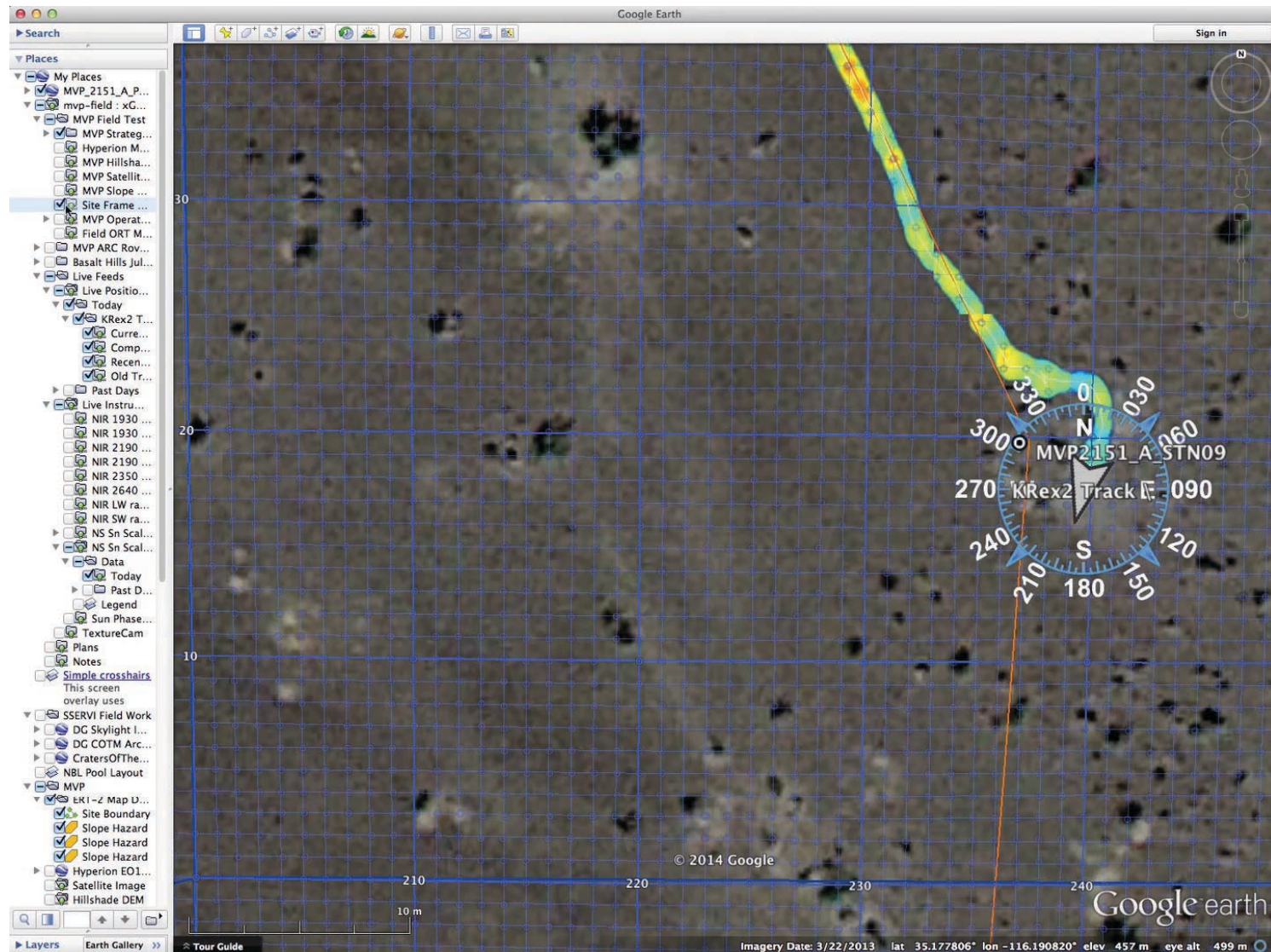
tolerance 0.6

isDirectional ☐  
If true, the rover should try to arrive at the station with its chassis oriented to the





# Exploration Ground Data System (xGDS)







Humans in space / Robot on the ground





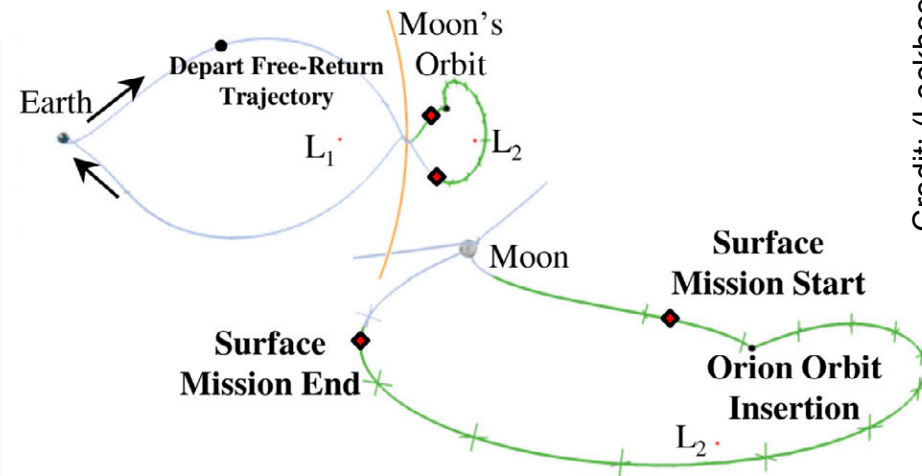
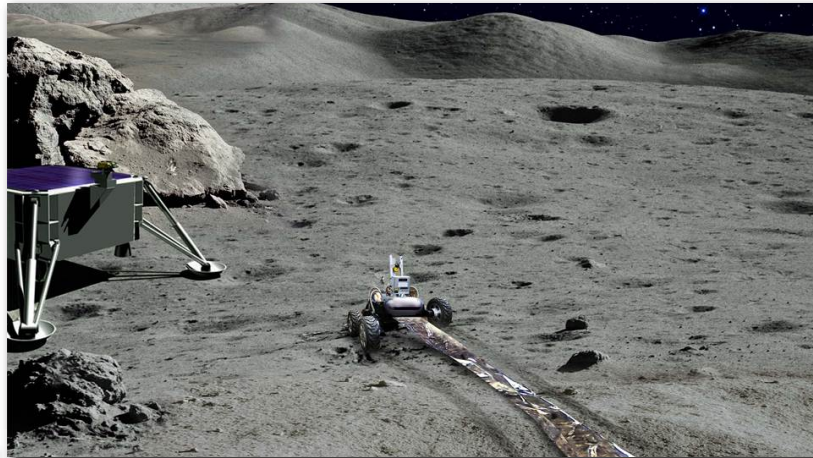
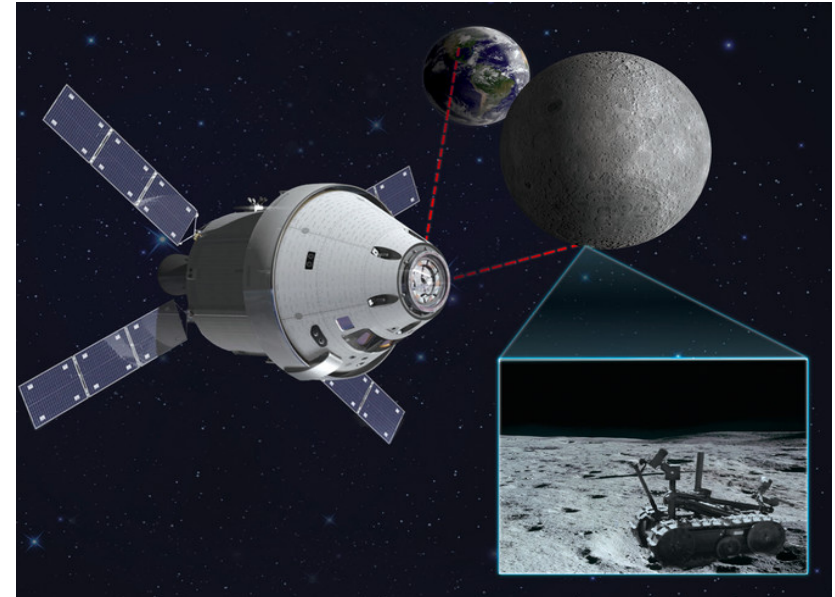
# “Fastnet” Lunar Libration Point Mission

## Orion MPCV at Earth-Moon L2 (EM-L2)

- 60,000 km beyond lunar farside
- Allows station keeping with minimal fuel
- Crew remotely operates robot
- Does not require human-rated lander

## Human-robot conops

- Crew remotely operates surface robot from inside flight vehicle
- Crew works in shirt-sleeve environment
- Multiple robot control modes



Credit: (Lockheed Martin / LUNAR)

# “Fastnet” Mission Simulation with ISS

## ISS Expedition 36

### Pre-Mission Planning



Ground teams plan out telescope deployment and initial rover traverses.

**Spring 2013**

### Surveying



Crew gathers information needed to finalize the telescope deployment plan.

**Chris Cassidy**

**17 June 2013**

### Telescope Deployment

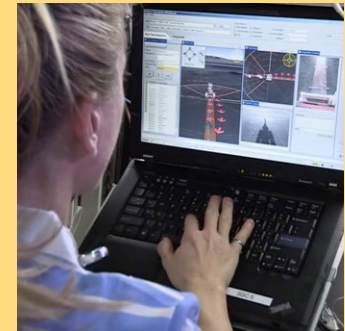


Crew monitors the rover as it deploys each arm of the telescope array.

**Luca Parmitano**

**26 July 2013**

### Telescope Inspection



Crew inspects and documents the deployed telescope for possible damage.

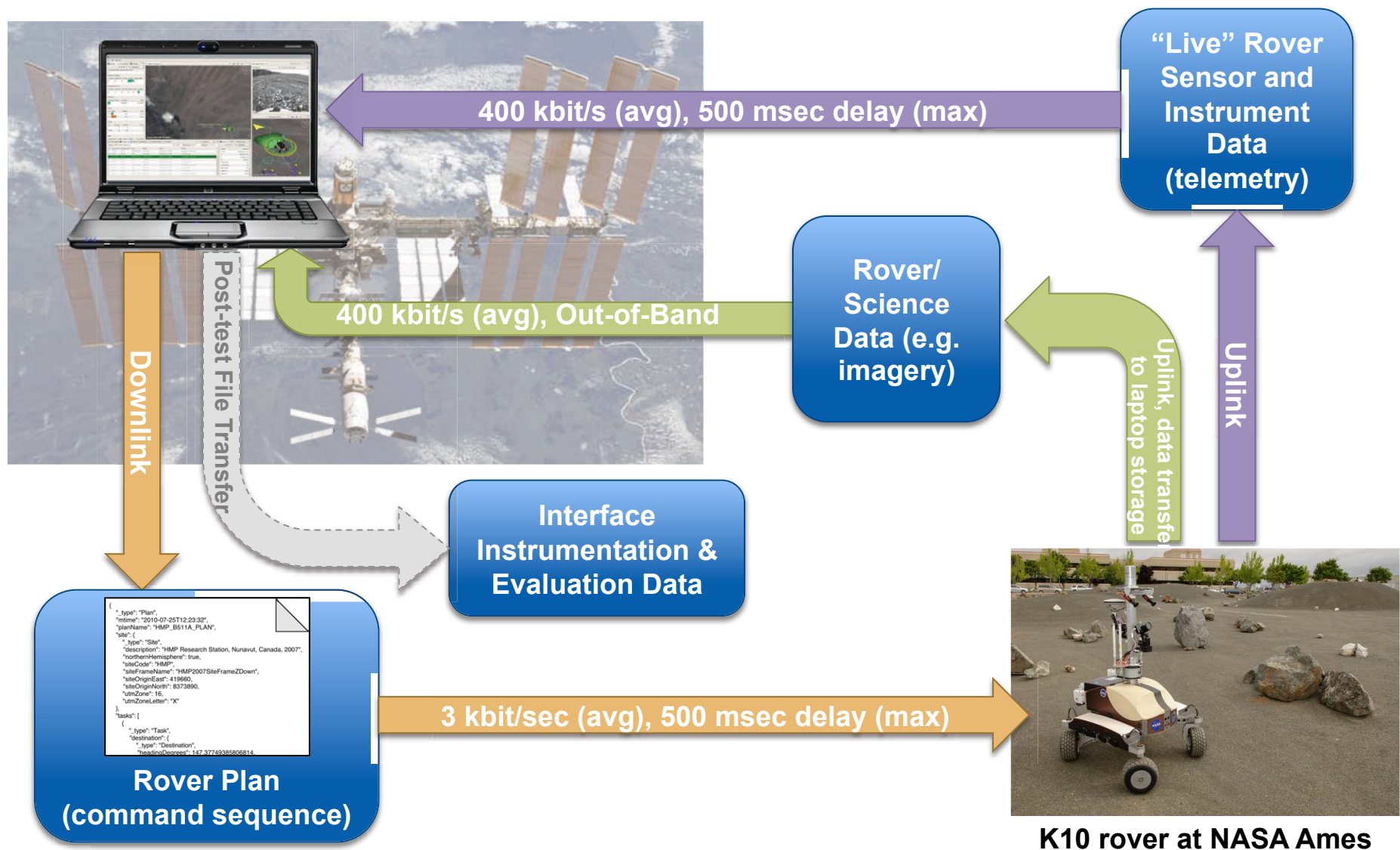
**Karen Nyberg**

**20 August 2013**

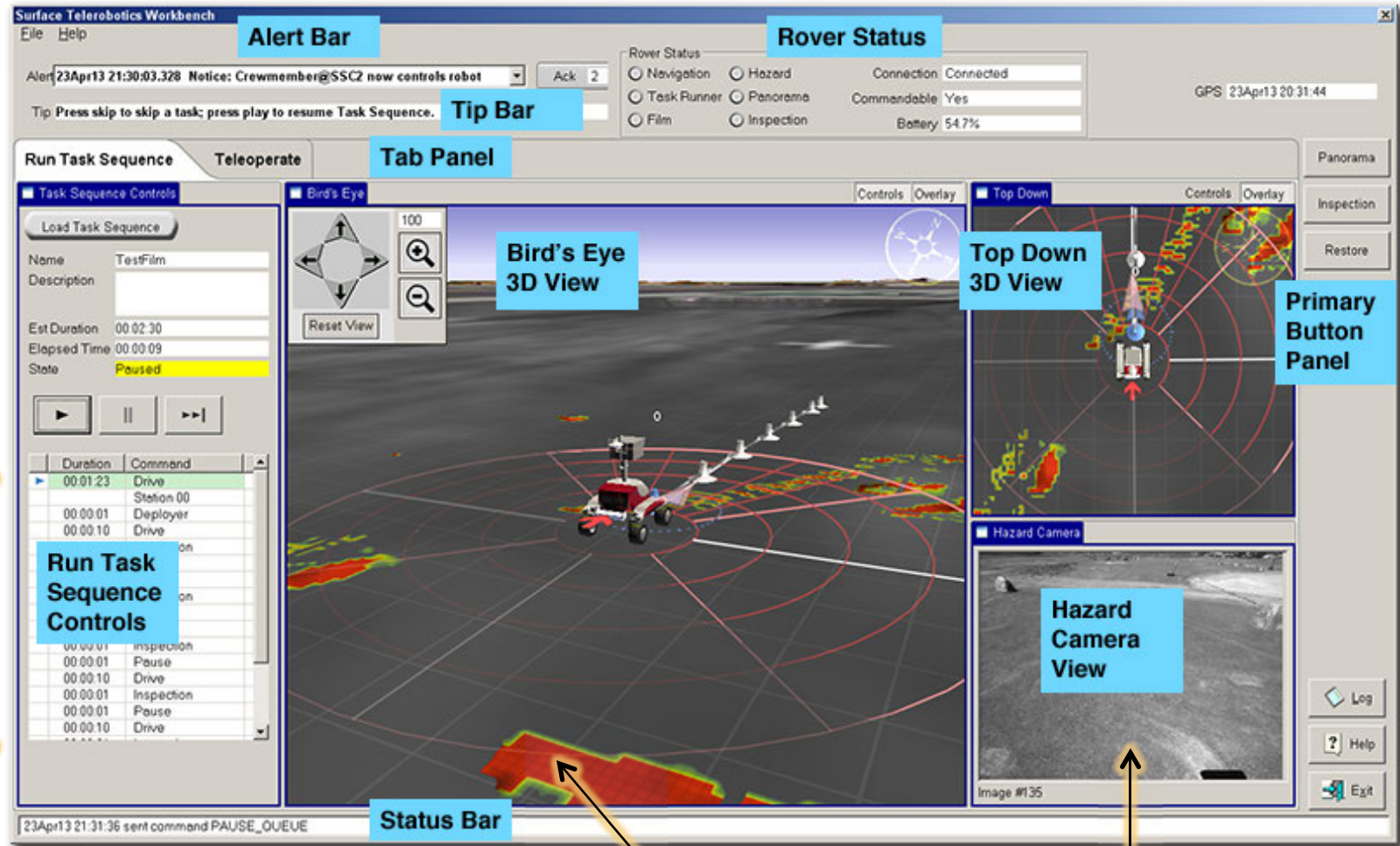




# ISS Test Setup



# Robot Interface (Supervisory Control)



Task Sequence

Terrain hazards

Rover camera display





# Crew-controlled Telerobotics (2013)

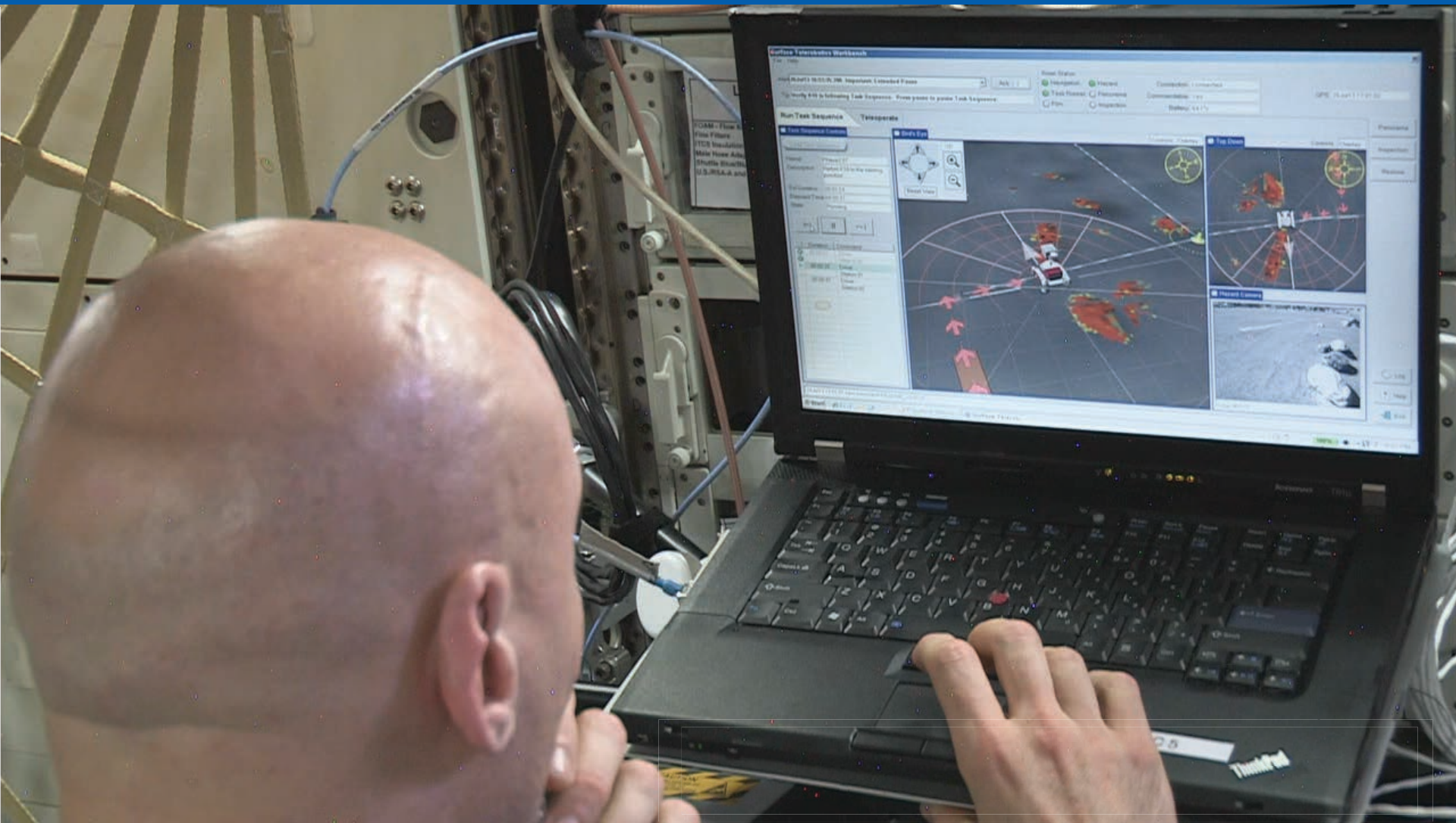
IDG



Mountain View, California



# Crew-controlled Telerobotics (2013)





# Assessment Approach

## Metrics

- **Mission Success:** % task sequences: completed normally, ended abnormally or not attempted; % task sequences scheduled vs. unscheduled
- **Robot Utilization:** % time robot spent on different types of tasks; comparison of actual to expected time on; did rover drive expected distance
- **Task Success:** % task sequences per session and per task sequence: completed normally, ended abnormally or not attempted; % that ended abnormally vs. unscheduled task sequences
- **Contingencies:** Mean Time To Intervene, Mean Time Between Interventions
- **Robot Performance:** expected vs. actual execution time on tasks

## Data Collection

- automatic
- **Data Communication:** direction (up/down), message type, total volume, etc.
  - **Robot Telemetry:** position, orientation, power, health, instrument state, etc.
  - **User Interfaces:** mode changes, data input, access to reference data, etc.
  - **Robot Operations:** start, end, duration of planning, monitoring, and analysis
  - **Crew Questionnaires:** workload (Bedford Scale), situation awareness (SAGAT)

M. Bualat, D. Schreckenghost, et al. (2014) “**Results from testing crew-controlled surface telerobotics on the International Space Station**”. Proc. of 12<sup>th</sup> I-SAIRAS (Montreal, Canada)



A person wearing a VR headset is interacting with a robotic arm. The person is wearing a white VR headset with "Virtual Research" written on it. The robotic arm is white and is positioned in front of a large screen. The screen displays a blue, textured surface. The background is dark, and there is a blue triangular structure visible in the upper left corner.

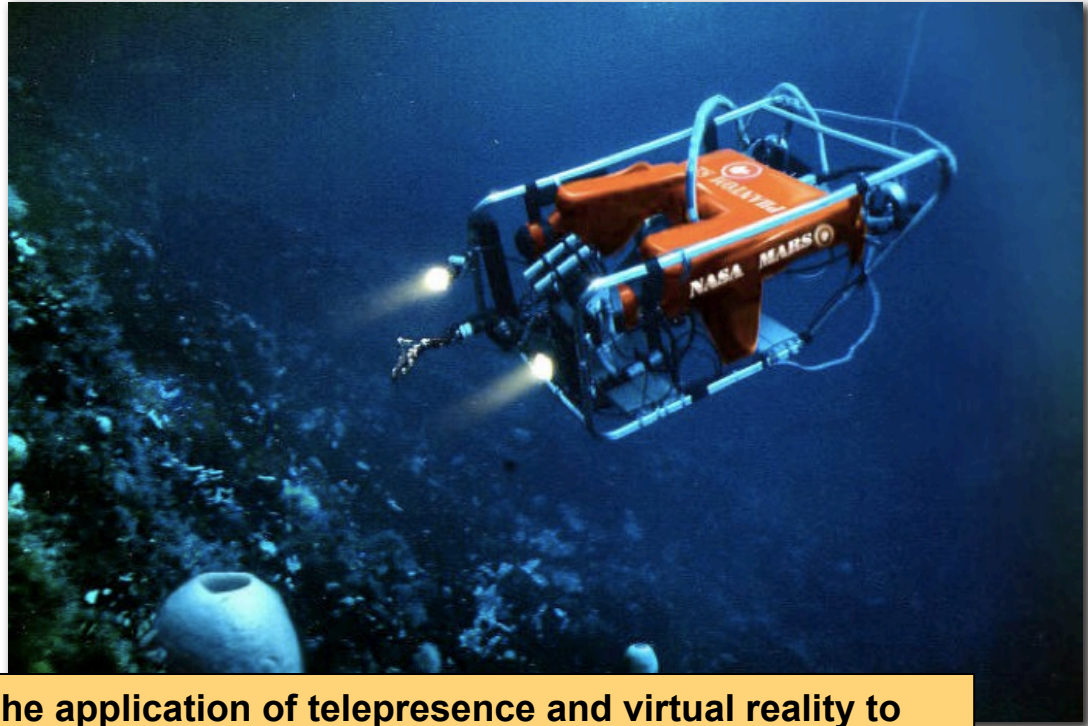
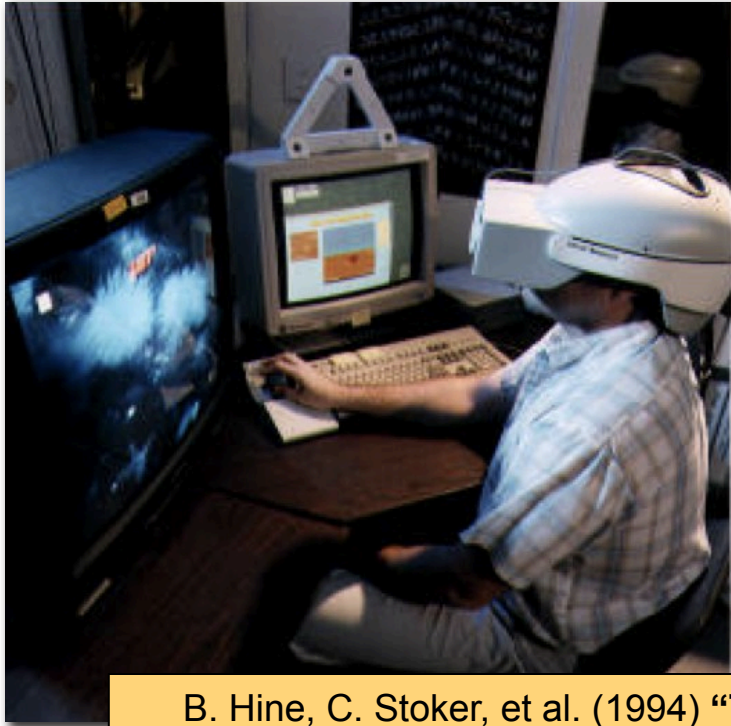
# Real-time Exploration Telerobotics



# Real-time Exploration Telerobotics

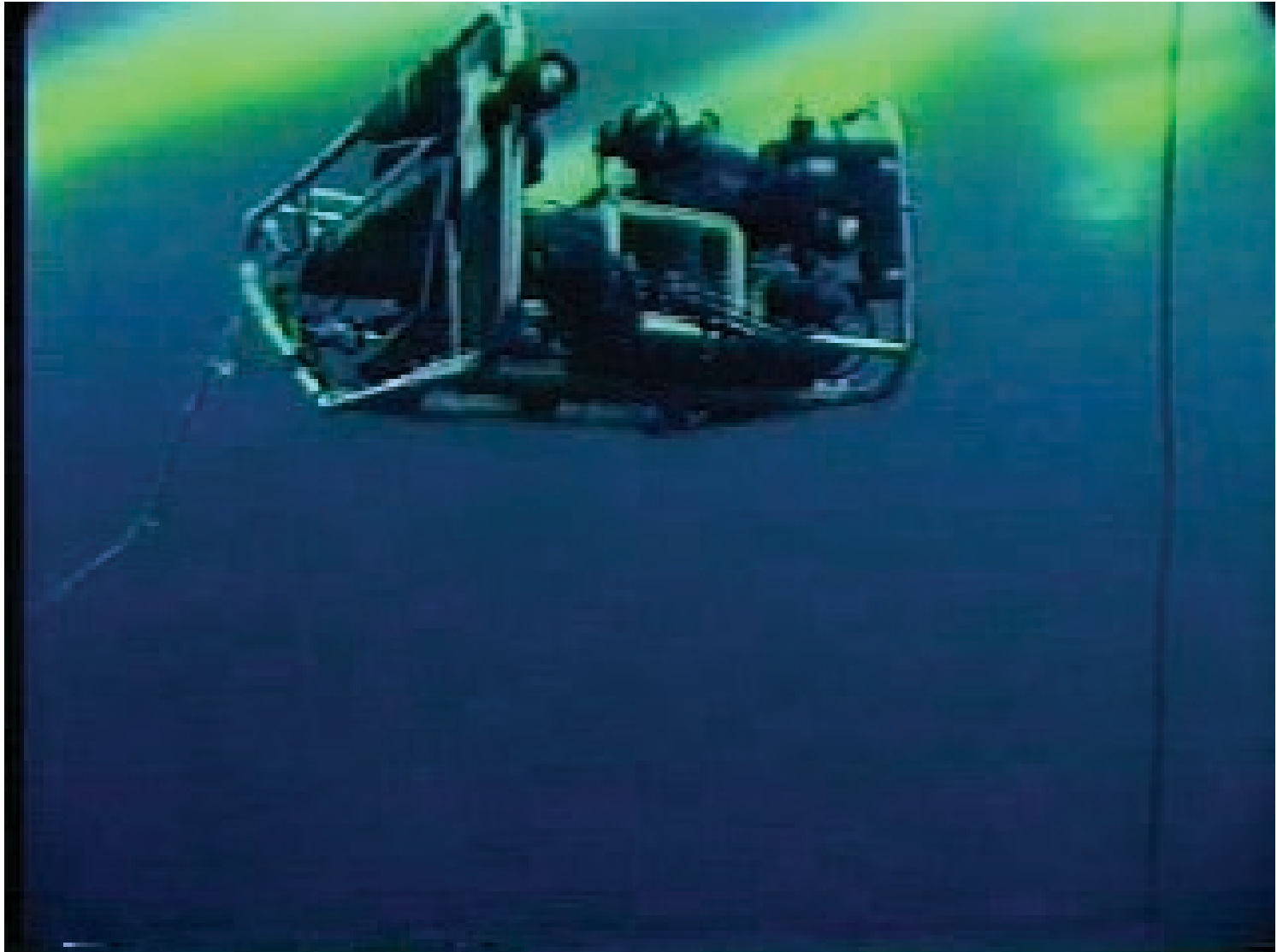
## Telepresence Remotely Operated Vehicle (TROV)

- Benthic ecology survey of McMurdo Sound (Nov-Dec 1993)
- Remote operations from NASA Ames via satellite (832 kbps downlink)
- Virtual environment + telepresence video (head tracked stereo display)



B. Hine, C. Stoker, et al. (1994) **“The application of telepresence and virtual reality to subsea exploration”**. Proc. of IARP workshop on mobile robots for subsea environments.

# Telepresence ROV (1993)





# Real-time Exploration Telerobotics

## Marsokhod at Kilauea

- Geologic mapping of Southwest Desert at Kilauea (Feb 1995)
- Remote operations from NASA Ames via satellite (T1 link)
- Virtual environment + telepresence video (stereo display)



C. Stoker and B. Hine. (1996) **“Telepresence control of mobile robots – Kilauea Marsokhod experiment”**. Proc. of AIAA 34th Aerospace Sciences Meeting.

# Marsokhod at Kilauea (1995)





# Lessons from TROV & Marsokhod

## Latency

- Latency is **only one factor** for remote exploration: type of science, instruments & data, cost, risk, staffing, robot capabilities, etc.
- Remote (robotic) exploration is not dominated by control latency. **Data collection** (with instruments), **analysis** (many steps), and **decision making** (strategic and tactical planning) are all far more significant.

## Spatial displays

- 3D visualizations is essential for most field studies
- **Head-mounted** and **stereo video** displays are **pseudo 3D**, not true 3D, which leads to many issues (accommodation errors, etc)
- High levels of **presence** can be achieved even with limited data.

## Real-time telerobotics

- Telepresence (immersive real-time presence) is **not a panacea**
- **Manual control** is imprecise and highly coupled to human performance (skills, experience, training)
- **Minimizing risk** is often (far more) important than efficiency.



# Questions?



## **Intelligent Robotics Group**

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